CLAIMS

1. A method of reducing distortion in a dynamically delayed digital sample stream of an imaging system, such method comprising the steps of:

delta-sigma modulating an input analog signal of the imaging system at a frequency above the Nyquist frequency of the input analog signal to generate a digital sample stream; and

changing a length of the sample stream while maintaining synchronism between a delta-sigma modulator and a demodulator of the system, thereby reducing intermodulation corruption.

2. The method as in claim 1 wherein the step of delta-sigma modulating an input analog signal further comprises adjusting a feedback magnitude within the modulator.

3. The method as in claim 2 wherein the step of changing the length of the sample stream further comprises deleting a sample of the sample stream.

4. The method as in claim 3 wherein the step of adjusting the feedback magnitude further comprises providing a null feedback for the deleted sample.

5. The method as in claim 2 wherein the step of changing the length of the sample stream further comprises inserting another sample into the sample stream.

6. The method as in claim 5 wherein the step of inserting another sample into the sample stream further comprises repeating a sample of the sample stream.

7. The method as in claim 6 wherein the step of adjusting the feedback magnitude further comprises providing a feedback multiplier of two for the repeated sample.

8. The method as in claim 1 wherein the step of changing the length of the sample stream further comprises inserting another sample into the sample stream.

9. The method as in claim 8 wherein the step of inserting another sample into the sample stream further comprises adjusting a digital level of the delayed samples.

10. The method as in claim 9 wherein the step of adjusting the digital level of the delayed samples further comprises dividing an original sample in half to produce a pair of divided samples and substituting the pair of divided samples for the original sample.

11. The method as in claim 9 wherein the step of adjusting the digital level of the delayed samples further comprises inserting a null sample into the sample stream, where a null sample has a magnitude half way between a high and low level of the digital sample stream level.

12. Apparatus for reducing distortion in a dynamically delayed digital sample stream of an imaging system, such apparatus comprising:

means for delta-sigma modulating an input analog signal of the imaging system at a frequency above the Nyquist frequency of the input analog signal to generate the digital sample stream; and

means for changing a length of the sample stream while maintaining synchronism between the means for delta-sigma modulating and a demodulator of the system.

13. The apparatus as in claim 12 wherein the means for delta-sigma modulating the sample stream further comprises means for adjusting a feedback magnitude.

14. The apparatus as in claim 13 wherein the means for changing the length of the sample stream further comprises means for deleting a sample of the sample stream

15. The apparatus as in claim 14 wherein the means for adjusting the feedback magnitude further comprises means for applying a feedback magnitude half-way between a high and low level for the deleted sample.

16. The apparatus as in claim 13 wherein the means for adjusting the length of the sample stream further comprises means for inserting another sample into the sample stream.

17. The apparatus as in claim 16 wherein the means for inserting another sample into the sample stream further comprises means for repeating a sample of the sample stream.

18. The apparatus as in claim 17 wherein the means for adjusting the feedback magnitude further comprises means for doubling a feedback magnitude for the repeated sample.

19. The apparatus as in claim 12 wherein the means for changing the length of the sample stream further comprises inserting another sample into the sample stream.

20. The apparatus as in claim 19 wherein the means for inserting another sample into the sample stream further comprises adjusting a digital level of the delayed samples.

21. The apparatus as in claim 20 wherein the means for adjusting the digital level of the delayed samples further comprises dividing an original sample in half to produce a pair of divided samples and substituting the pair of divided samples for the original sample

22. The apparatus as in claim 20 wherein the means for adjusting the digital level of the delayed samples further comprises inserting a null sample into the sample stream, where a null sample has a magnitude half way between a high and low level of the digital sample stream.

23. Apparatus for reducing distortion in a dynamically delayed digital sample stream of an imaging system, such apparatus comprising:

a delta-sigma modulator which modulates an input analog signal of the imaging system at a frequency above the Nyquist frequency of the input analog signal to generate the digital sample stream; and

a sample stream controller which changes a length of the sample stream to delay a portion of the sample stream while maintaining synchronism between the means for delta-sigma modulating and a demodulator of the system.

24. The apparatus as in claim 23 wherein the delta-sigma modulator which modulates the input analog signal further comprises a feedback controller.

25. The apparatus as in claim 24 wherein the sample stream controller which changes the length of the sample stream further comprises a first programmable shift register which deletes a sample of the sample stream

26. The apparatus as in claim 25 wherein the feedback controller further comprises an arithmetic unit which applies a feedback magnitude half way between a normal high and low level for the deleted sample.

27. The apparatus as in claim 24 wherein the sample stream controller which adjusts the length of the sample stream further comprises a second programmable shift register which inserts another sample into the sample stream.

28. The apparatus as in claim 27 wherein the sample stream controller which inserts another sample into the sample stream further comprises a memory which together with the second programmable shift register repeats a sample of the sample stream.

29. The apparatus as in claim 28 wherein the feedback controller which adjusts the feedback magnitude further comprises a feedback doubler which provides a feedback magnitude of two for the repeated sample.

30. The apparatus as in claim 23 wherein the sample stream controller which adjusts the length of the signal stream further comprises a second programmable shift register which inserts another sample to the sample stream further and a divider which divides an original sample in

half to produce a pair of divided samples and substitutes the divided samples for the original sample and the inserted sample.

31. The apparatus as in claim 27 wherein the means for inserting another sample to the sample stream further comprises means for inserting a null sample into the sample stream.

32. A method of creating an ultrasonic image in an ultrasonic imaging system, such method comprising the steps of:

retrieving a delta-sigma modulated transmit signal stream;

delaying at least some samples of the transmit signal stream to form a steered beam;

converting the at least some samples into an analog sample stream;

buffering the analog sample stream and driving a plurality of transducer elements with the buffered analog signal stream;

detecting an end of the transmit signal stream;

switching a plurality of multiplexers to receive a plurality of return analog signal streams from the transducer elements;

delta-sigma modulating the return analog signal streams to form a plurality of digital signal streams;

dynamically delaying the digital signal streams;

summing the delayed digital signal streams;

basebanding and filtering the dynamically delayed digital signal stream.

33. The method as in claim 32 wherein the step of delta-sigma modulating an input analog signal further comprises adjusting a feedback magnitude within the modulator.

34. The method as in claim 33 wherein the step of changing the length of the sample stream further comprises deleting a sample of the sample stream.

35. The method as in claim 34 wherein the step of adjusting the feedback magnitude further comprises providing a null feedback for the deleted sample.

1 36. The method as in claim 33 wherein the step of changing the length of the sample stream
2 further comprises inserting another sample into the sample stream.

1 37. The method as in claim 36 wherein the step of inserting another sample into the sample
2 stream further comprises repeating a sample of the sample stream.

1 38. The method as in claim 37 wherein the step of adjusting the feedback magnitude further
2 comprises providing a feedback multiplier of two for the repeated sample.

1 39. The method as in claim 32 wherein the step of dynamically delaying the sample stream
2 further comprises inserting another sample into the sample stream.

1 40. The method as in claim 39 wherein the step of inserting another sample into the sample
2 stream further comprises adjusting a digital level of the delayed samples.

1 41. The method as in claim 40 wherein the step of adjusting the digital level of the delayed
2 samples further comprises dividing an original sample in half to produce a pair of divided
3 samples and substituting the pair of divided samples for the original sample.

1 42. The method as in claim 40 wherein the step of inserting another sample of the sample
2 stream further comprises inserting a null sample into the sample stream.

1 43. The method as in claim 32 further comprising low-pass filtering the transmitted sample
2 streams.

1 44. The method as in claim 32 further comprising time gain compensating the return analog
2 signal for attenuation as a function of distance.

1 45. Apparatus for creating an ultrasonic image in an ultrasonic imaging system, such
2 apparatus comprising:

means for storing and retrieving a delta-sigma modulated transmit signal stream;

means for delaying at least some samples of the transmit signal stream to form a statically focused and steered transmit beam and for delaying at least some samples of a plurality of digital signal streams from a delta-sigma modulator to form a dynamically focused and steered receive beam;

means for detecting an end of the transmit signal stream;

means for switching a transducer for receiving a plurality of analog signal streams returned from the transducer;

means for delta-sigma modulating the analog signal streams to form the digital signal streams which are dynamically delayed in the means for delaying;

means for maintaining synchronism between the delta-sigma modulator and a delta-sigma demodulator in response to each change in the dynamic delay of the digital signal streams;

means for summing a corresponding set of samples of the modulated and delayed digital signal streams;

means for basebanding and filtering the summed digital signal streams.

46 The apparatus as in claim 45 wherein the apparatus for creating an ultrasonic imager further comprises a handheld probe.

47. The apparatus as in claim 45 wherein the means for delta-sigma modulating the input analog signal streams further comprises adjusting a feedback magnitude within the modulator.

48. The apparatus as in claim 47 wherein the means for dynamically delaying the digital signal streams further comprises means for repeating a sample of the digital sample stream.

49. The apparatus as in claim 48 wherein the means for varying a feedback level of the delta-sigma modulator further comprises means for doubling a feedback level for the repeated bit.

50. The method as in claim 47 wherein the step of changing the length of the sample stream further comprises deleting a sample of the sample streams.

51. The method as in claim 50 wherein the step of adjusting the feedback magnitude further comprises providing a null feedback for the deleted sample.

52. The apparatus as in claim 45 wherein the means for dynamically delaying the digital signal streams further comprises means for inserting a null sample into the digital sample streams.

53. The apparatus as in claim 45 wherein the means for dynamically delaying the digital signal stream further comprises means for dividing an original sample of the digital sample stream in half and placing half of the sample in an original sample location and half in a newly created location adjacent the original sample location.

54. The apparatus as in claim 45 further comprising means for low-pass filtering the transmitted sample streams.

55. The apparatus as in claim 45 further comprising means for time gain compensating the return analog signal streams for attenuation as a function of distance.

56. Apparatus for creating an ultrasonic image in an ultrasonic imaging system, such apparatus comprising:

a memory which stores a delta-sigma transmit signal stream;

a programmable register which delays at least some samples of the transmit signal stream to form a statically focused steered transmit beam and at least some samples of a return digital signal stream to form a dynamically focused and steered receive beam;

a counter which detects an end of the transmit signal stream;

a digital to analog converter which converts the transmit signal stream to an analog signal stream;

a switch which switches a transducer for receiving a return analog signal stream;

a delta-sigma modulator which delta-sigma modulates the return analog signal streams to form the digital signal streams which is dynamically delayed in the means for delaying;

an adder network that sums the digital signal streams;

a mixer which demodulates the summed digital signal streams to baseband; and

a low-pass filter which low-pass filters the basebanded signal to remove delta-sigma quantization noise.

57. The apparatus for creating an ultrasonic imager as in claim 56 further comprising a handheld probe.

58. The apparatus as in claim 56 wherein the programmable register which dynamically delays the digital signal streams further comprises a divider circuit which divides a digital value of an original sample of the digital bit streams in half and places a first halved sample in an original sample location and a second halved sample in a newly created sample location adjacent the original sample location.

59. Apparatus as in claim 56 wherein the programmable register which delays at least some samples further comprises a circuit that recodes digital values and inserts a null sample

60. The apparatus as in claim 56 further comprising a low pass filter which low pass filters the transmitted sample streams.

61. The apparatus as in claim 56 further comprising a time gain compensator which time gain compensates the return analog signal for attenuation as a function of distance.

62. Apparatus for creating an ultrasonic image in an ultrasonic imaging system, such apparatus comprising:

a memory which stores a delta-sigma transmit signal stream;

a programmable register which delays at least some samples of the transmit signal stream to form a statically focused steered transmit beam and at least some samples of a return digital signal stream to form a dynamically focused and steered receive beam;

a counter which detects an end of the transmit signal stream;

a digital to analog converter which converts the delayed signal stream to an analog signal stream;

a buffer which buffers the analog signal stream and which drives a portion of a transducer array;

a switch which switches a transducer for receiving a return analog signal stream;

a delta-sigma modulator which delta-sigma modulates the return analog signal stream to form the digital signal stream which is dynamically delayed in the programmable register;

a multiplexer which varies a feedback level of the delta-sigma modulator for each change in the dynamic delay of the digital signal stream;

an adder network that sums the digital signal streams;

a mixer which demodulates the summed signal stream; and

a filter which low-pass filters the mixed signal stream.

63. The apparatus for creating an ultrasonic image as in claim 62 further comprising a handheld probe.

64. The apparatus as in claim 62 wherein the programmable register which dynamically delays the digital signal stream further comprises a latch which increases a length of the signal stream by repeating a sample of the digital sample stream.

65. The apparatus as in claim 64 wherein the multiplexer which varies a feedback level of the delta-sigma modulator further comprises a multiplier which provides twice a normal feedback level for the repeated sample.

66. The apparatus as in claim 62 wherein the programmable register which dynamically delays the digital signal stream further comprises a shift controller which decreases a length of the digital signal streams by deleting a sample of the digital sample stream when the delay must change

67. The apparatus as in claim 66 wherein the multiplexer which varies a feedback level of the delta-sigma modulator further comprises an analog voltage halfway between other valid feedback levels for the deleted sample.

68. A method of improving system noise performance of a delta-sigma based dynamically delayed beamformer receiving a plurality of analog signal streams from a plurality of transducers of a transducer array and providing an amplitude modulated output signal corresponding to a signal intensity as a function of range from the transducer array, such method comprising the steps of:

downconverting the plurality of analog signal streams on a plurality of processing channels by mixing each input signal stream of the plurality of analog input signal streams with a periodic signal having a fundamental frequency greater than zero Hertz but less than twice a carrier center frequency of the received analog signal streams;

digitizing each mixed signal stream within a delta-sigma modulator;

dynamically delaying a corresponding set of samples among the digitized signal streams within independent delay lines to compensate each sample of the corresponding set of samples for a sample source's geometric origin relative to a desired dynamic receive focus;

dynamically adjusting the phase of the periodic signal on each channel of the plurality of processing channels based upon a total delay applied to the sample stream of that channel;

summing the corresponding set of delayed samples; and

basebanding and low pass filtering the stream of summed samples to provide an output signal whose amplitude corresponds to the signal intensity of the formed beam as a function of range.

69. The method as in claim 68 further comprising the step of time gain compensating each analog signal of each analog signal stream of the plurality of analog signal streams based upon a distance of the signal from the transducer.

70. The method as in claim 68 wherein the step of digitizing each mixed signal stream within a delta-sigma modulator further comprising sampling the mixed signal stream above the Nyquist frequency for the signal stream.

71. A programmable charge coupled device complementary delay device comprising:

a first delay stage having a first delay along a first path through the first delay stage and a second delay along a second path through the delay stage;

a second delay stage having a third delay along a first path through the second delay stage and the second delay along the second path through the second delay stage; and

a crossover device coupled between the first and second delay stages having a first and a second position, the crossover device forming a first conductive path from the first path of the first delay stage to the first path of the second delay stage and a second conductive path from the second path of the first stage to the second path of the second stage when in the first position and forming a first conductive path from the first path of the first delay stage to the second path of the second delay stage and a second conductive path from the second path of the first stage to the first path of the second stage when in the second position

72. The programmable charge coupled device complementary delay device as in claim 71 further comprising a common input to the first and second paths through the first delay stage.

73. The programmable charge coupled device complementary delay device as in claim 71 wherein the common input to the first and second paths through the first delay stage further comprising a device input.

74 The programmable charge coupled device complementary delay device as in claim 71 wherein the first delay is substantially equal to twice the second delay.

75. The programmable charge coupled device complementary delay device as in claim 71 wherein the third delay is substantially equal to twice the first delay.

76. The programmable charge coupled device complementary delay device as in claim 71 further comprising a plurality of additional delay stages and crossover devices with a delay in the first path substantially equal to twice a delay of the first path of a previous delay stage and a delay in the second path substantially equal to the second delay.

77. The complementary delay device as in claim 71 where the charge coupled device is a digital storage device.

78. A method of gathering spatial information, such method comprising the steps of:
retrieving an oversampled delta-sigma modulated sequence for a selected set of channels of a transducer array from a memory;
delaying the sequence of each channel of the selected set within a transmit/receive delay register to steer a transmitted ultrasonic beam;
counting a number of samples of the delta-sigma modulated sequence to detect an end of a transmit sequence;
detecting a reflected signal at the end of the transmit sequence on each channel of the selected set of channels;
delta-sigma modulating the detected signal of each channel;
dynamically delaying a corresponding set of delta-sigma modulated samples from among the channels of the modulated detected signals in the transmit/receive delay register;
summing a corresponding set of delta-sigma modulated values to provide an output signal whose amplitude corresponds to a signal intensity of the formed beam as a function of range.

79. The method of gathering spatial information as in claim 78 wherein the step of beamforming a received signal in the transmit/receive delay register further comprises using a series of delay and addition stages in the transmit/receive delay register to partially beamform elevational and azimuthal transducer array elements.

80. The method of gathering spatial information as in claim 78 further comprising premodulating the detected reflected signal.

81. The method of gathering spatial information as in claim 78 further comprising the step of time gain compensating the detected reflected signal.

82. The method of gathering spatial information as in claim 78 further comprising the step of differentially driving a set of signal amplifiers of an ultrasonic transducer array with the oversampled delta-sigma modulated sequence.

83. The method of gathering spatial information as in claim 78 further comprising alternating a polarity of a set of transducer array elements to reduce common mode noise.

84. The method of gathering spatial information as in claim 78 further comprising remodulating a summed output of the beamformer with a delta-sigma modulator.

85. The method of gathering spatial information as in claim 78 further comprising detecting a reflected signal over a two-dimensional array.

86. The method of gathering spatial information as in claim 78 further comprising dynamically delaying the delta-sigma modulated signal using a barrel shifter.

87. The method of gathering spatial information as in claim 78 further comprising adjusting a delay period and repeating the steps of detecting, delta-sigma modulating, dynamically delaying and summing.

88. Apparatus for gathering spatial information, such apparatus comprising:

means for retrieving an oversampled delta-sigma modulated sequence for a selected set of channels of a transducer array from a memory;

means for delaying the sequence of each channel of the selected set within a transmit/receive delay register to steer a transmitted ultrasonic beam;

means for counting a number of samples of the delta-sigma modulated sequence to detect an end of a transmit sequence;

means for detecting a reflected signal at the end of the transmit sequence on each channel of the selected set of channels;

means for delta-sigma modulating the detected signal of each channel;

means for dynamically delaying a corresponding set of delta-sigma modulated samples from among the channels of the modulated detected signals in the transmit/receive delay register;

means for summing a corresponding set of delta-sigma modulated values to provide an output signal whose amplitude corresponds to a signal intensity of the formed beam as a function of range.

89. The apparatus for gathering spatial information as in claim 88 wherein the means for beamforming a received signal in the transmit/receive delay register further comprises means for using a series of delay and addition stages in the transmit/receive delay register to partially beamform elevational and azimuthal transducer array elements.

90. The apparatus for gathering spatial information as in claim 88 further comprising means for premodulating the detected reflected signal.

91. The apparatus for gathering spatial information as in claim 88 further comprising means for time gain compensating the detected reflected signal.

92. The apparatus for gathering spatial information as in claim 88 further comprising means for differentially driving a set of signal amplifiers of an ultrasonic transducer array with the oversampled delta-sigma modulated sequence.

93. The apparatus for gathering spatial information as in claim 88 further comprising means for alternating a polarity of a set of transducer array elements to reduce common mode noise.

94. The apparatus for gathering spatial information as in claim 88 further comprising means for remodulating a summed output of the beamformer with a delta-sigma modulator.

95. The apparatus for gathering spatial information as in claim 88 further comprising means for detecting a reflected signal over a two-dimensional array.

96. The apparatus for gathering spatial information as in claim 88 further comprising means for dynamically delaying the delta-sigma modulated signal using a barrel shifter.

97. The apparatus for gathering spatial information as in claim 88 further comprising means for adjusting a delay period and for forming a beam in a different direction.

98. The apparatus for gathering spatial information as in claim 88 further comprising an analog multiplexer which couples the detected reflected signal between the means for detecting and the means for delta-sigma modulating.

99. The apparatus for gathering spatial information as in claim 88 further comprising a plurality of premodulators coupling between the analog multiplexer and means for delta-sigma modulating.

100. The apparatus for gathering spatial information as in claim 88 further comprising a shared analog amplification circuit which buffers the plurality of premodulators.